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EFFECTS OF A SIMULATED MARTIAN MISSION ON THE MECHANICAL PROPERTIES OF DACRON PARACHUTE MATERIAL

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16. Abstract

The effects of a simulated Martian mission on the mechanical properties of 67.8-g/m^2 (2 oz/yd^2) Dacron Type 55 parachute material was determined by uniaxial tensile testing at a constant strain rate for four groups of samples. The first group was exposed to the mission environments of ethylene oxide decontamination, dry heat sterilization, vacuum, and a simulated Martian atmosphere and tensile tested in situ. The second group was a control group and was stored and tested at 24° C (75° F) and 45 percent relative humidity. The third and fourth groups were exposed to selected mission environments.

The results of this investigation indicate that the exposure of Dacron to these mission environments will induce changes to the mechanical properties of this material. The change in mechanical properties does not exceed -8 percent in maximum stress, -23 percent in elongation at maximum stress, -29 percent in total energy, -12 percent for initial modulus, and +9 percent for final modulus. Vacuum had the largest single effect on the mechanical properties of the parachute material.

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EFFECTS OF A MARTIAN MISSION ON THE MECHANICAL PROPERTIES OF DACRON PARACHUTE MATERIAL

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SUMMARY

The effects of a simulated Martian mission on the mechanical properties of 67.8-g/m^2 (2 oz/yd^2) Dacron Type 55 parachute material was determined by evaluating the test results from four groups. The first group was a mission environment group whereby the parachute material was exposed to ethylene oxide decontamination, dry heat sterilization, a vacuum, and a simulated Martian atmosphere in sequence and without interruption. At the completion of each environmental exposure, a specific number of samples were uniaxially tensile tested in situ. The second group was a control group whereby the Dacron samples were stored and tested in an atmospheric environment of 24° C (75° F) and 45 percent relative humidity. The third and fourth groups were special studies to determine the effect of dry heat sterilization and vacuum in combination and separately.

The results from the test program indicate that the sequential exposure of Dacron parachute material to these mission environments will induce a change to the mechanical properties of this material. The magnitude of change did not exceed -8 percent in maximum stress, -23 percent in elongation, -29 percent in total energy, -12 percent in initial modulus, and +9 percent in final modulus. The largest single effect, of the four mission environments tested, occurred after exposure to vacuum.

INTRODUCTION

A planetary exploration program that requires a spacecraft lander may create the need for a deceleration device. Material studies in both references 1 and 2 have indicated that Dacron was a candidate fabric because of its high strength and heat stability. Langley Research Center showed the feasibility of utilizing a parachute as a spacecraft decelerator in the Planetary Entry Parachute Program (PEPP). (See ref. 3.) Dacron was the material used in the PEP Program and part of the parachute fabric originally purchased for the PEPP parachutes was used in this test program. (See table 1.)

Some investigators (refs. 4 and 5) have studied the single effects of temperature and vacuum on candidate textile materials. Others (refs. 6 and 7) have studied the effects of dry heat sterilization followed by ethylene oxide treatment on fabrics, but have removed the material from the environment to facilitate tensile testing. Recent environmental studies (ref. 8) have demonstrated that in situ testing is necessary to obtain valid measurements of environmentally induced effects.

To engineer a decelerator device, one must know the mechanical behavior of the material after exposure to the various mission environments both collectively and individually. This investigation objectively meets this criteria by the exposure of Dacron parachute material to the prelaunch environments of ethylene oxide and dry heat sterilization followed by exposure to the flight environments of vacuum and Martian atmosphere. (See ref. 9.) After the exposure of the material to each mission environment, a group of samples was uniaxially tensile tested at a constant strain rate. The results obtained from the mission simulation were then compared with the results obtained from an atmospheric controlled test to measure the induced effects of the environmental sequence. In addition to the sequential environment effects, several single effects are reported.

Values are given in both SI and U.S. Customary Units. The measurements and calculations were made in U.S. Customary Units.

ABBREVIATIONS

ETO	ethylene oxide
DHS	dry heat sterilization
MA	Martian atmosphere
PV	post vacuum
VAC	vacuum

TEST PROGRAM

In order to determine the combined and individual effects of a Martian mission on the mechanical properties of Dacron parachute material, the test program was divided into four parts – test I, test II, test III, and test IV. The test parameters for each mission environment and the sequence in which the material was exposed and tested are given in table 2. As can be seen from the description of each test that follows, the study included the combined effects of a typical Martian mission and each environment separately.

Test I covered the exposure of samples to ethylene oxide, dry heat sterilization, vacuum, and a simulated Martian atmosphere that represented a mission sequence. At the completion of each environmental exposure, a group of samples was tensile tested in situ.

Test II was a control test whereby a group of samples were stored and tested in a controlled atmospheric environment of 24° C (75° F) and 45 percent relative humidity.

Test III consisted of exposing a group of samples to the environment of dry heat sterilization followed by a vacuum test. This test was a measure of the single environment of sterilization as well as a combination of two mission environments.

Test IV covered the exposure of a group of samples to the flight environment of vacuum for a 30-day period. Although 30 days was not a realistic time profile for a Martian mission, it would be indicative of any change or trend in mechanical properties.

Apparatus

Three major apparatus were used to expose the Dacron parachute material to the various mission environments: ethylene oxide sterilization facility, the Langley 150-cubic-foot space vacuum facility, and an atmosphere control facility. The details of each of these apparatus are given in the next three sections.

Ethylene oxide apparatus.- The ethylene oxide (ETO) decontamination was conducted in the facilities shown in figure 1. The major items of the apparatus are the sterilizer, the Class 1A storage cylinder containing the decontaminant as 12 percent ETO and 88 percent Freon-12, and the peripheral control equipment. The Dacron samples, 2.5 by 7.6 cm (1 by 3 in.), were placed in a chamber whose capacity was 41 by 41 by 66 cm (16 by 16 by 26 in.).

Langley 150-cubic-foot space vacuum facility.- The Langley 150-cubic-foot space vacuum facility performed three environmental and one mechanical function throughout this investigation. The chamber, 2.3 m (7.5 ft) in diameter and 3.7 m (12 ft) long, and the uniaxial tensile apparatus are schematically shown in figure 2. An interior view of the actual facility is shown in figure 3. The pumping equipment to evacuate the chamber consists of one 14.2-m^3/min (500 ft^3/min) roughing pump, four 25.4-cm (10 in.) booster diffusion pumps, and four 81.3-cm (32 in.) diffusion pumps. Further details pertaining to the performance of the vacuum chamber are given in reference 10.

The tensile apparatus consisted of a 45-position carousel-type storage table that had two parallel, unaxial aluminum disks, 76 cm (30 in.) in diameter. The lower disk had a bevel gear attached to it that was actuated by a magnetic feedthrough located on the exterior of the vacuum chamber. This mechanism permitted the samples to be rotated to a testing position that was in line with the pulling jaw. (See fig. 3.) To the pulling jaw were attached two 445-N (100 lb) load cells that were linked to a bellows feedthrough which connected to a loading frame located external to the vacuum chamber. Of the 45 positions, one was used to store the test weight and another position stored the linearity spring. The remaining 43 positions were used to store the test samples. Further details pertaining to this apparatus are given in reference 11.

Dry heat sterilization of the test samples was carried out in this facility by the use of resistant heaters, and the general arrangement is schematically shown in figure 4. The equipment consisted of four 5-kW calrod heaters that were mounted around the periphery of the storage table. The temperature of the samples was monitored by four No. 30 gage iron-constantan thermocouples that were located directly behind the sample at positions 90° apart around the carousel. It was structurally impossible to attach a thermocouple to the fabric without changing its physical characteristics. After calibrating them at the freezing and boiling points of water, it was assumed that, as long as the four thermocouples were reading together, they were within acceptable limits for monitoring the temperature of the samples. A single thermocouple was attached to the carousel to monitor the temperature of the system. The output of the thermocouples was recorded on a multipoint temperature recorder located external of the vacuum chamber.

The simulated Martian atmosphere (ref. 9) was stored in a standard 0.085-m^3 (3 ft^3), 4.14-MN/m^2 (600 psig) cylinder and was admitted into the vacuum chamber by means of a reducing valve and copper tubing.

Atmospheric control facility.- The room where the control group of samples were stored and tested was a Class 100 clean room. Here the samples were kept under the controlled environment of 24° C (75° F) and 45 percent relative humidity.

Materials

The following materials were used in this investigation:

Dacron: The 67.8-g/m^2 (2 oz/yd^2) Dacron Type 55 was obtained in a bulk roll that had the nominal specifications as given in table 1. The rough samples were cut from the bulk roll in accordance with the layout shown in figure 5. The samples were further prepared by raveling to 120 strand count in the warp direction in accordance with ASTM standards of reference 12. To obtain proper alinement and reproducibility, the test samples were mounted in specially designed jaws as shown in figure 6 and by following the procedure given in appendix A.

Ethylene oxide: The ethylene oxide used in decontamination treatment consisted of 12 percent ETO and 88 percent Freon-12.

Martian atmosphere: The simulated Martian atmosphere was patterned after Model I, lower atmosphere of Mars (ref. 9). The gas mixture used in this investigation had a composition of 74.4 percent CO_2, 12.8 percent nitrogen, and 12.8 percent argon. The gas was supplied from commercial sources within ±0.9 percent of the required analysis.

TEST PROCEDURE

The test procedure followed throughout this investigation is divided into two parts; the first covers the two types of tensile tests, and the second covers the procedure required for each mission environment.

Tensile Tests

The tensile tests were conducted in two separate uniaxial tensile apparatus.

Vacuum chamber tests.- The first uniaxial tensile apparatus, shown in figure 3, was in the Langley 150-cubic-foot space vacuum facility and was utilized to test a group of samples after exposure to each environment being studied. Forty-three test samples (prepared by the procedure given in appendix A) were placed in positions around the periphery of the carousel. The load cell was calibrated by the test weight and a linearity check was made by the spring. At time zero, all 43 samples were exposed to the first environment. After the first exposure, 5 samples were uniaxially tensile tested at a head speed of 5 cm/min (2 in./min). The remaining 38 samples were exposed to the second environment, and at the completion of this exposure, 5 more samples were tensile tested. Then, 33 samples were exposed to the vacuum environment, and at various intervals of time (days), groups of 5, 5, 4, 4, and 5 samples were tensile tested. The remaining 10 samples were then exposed to the fourth environment. After 2 min of exposure, 5 samples were tensile tested to cover the period of parachute deployment, and 24 hr later, the final 5 samples were tensile tested. This procedure, therefore, provided mechanical property determinations on the parachute material in the proper mission sequence and without interruption which accomplished the desired in situ simulation. This procedure was used for tests I, III, and IV (table 2).

Control test (test II).- The second tensile test apparatus was in an atmospheric environment room where the temperature and humidity were controlled. The mechanical properties determined under these conditions served as a base line for comparing the results obtained from exposure to the various mission environments. The control test was made by storing the samples under the controlled environment of 24° C (75° F) and

45 percent relative humidity, and at intervals of 7, 14, and 21 days, 30 samples were assembled in tensile jaws (see the procedure in appendix A) and tested by the same procedure as that used for the vacuum chamber tests.

Mission Environments

The test procedure that was used to expose the Dacron parachute material to the various mission environments is given in the following sections.

ETO decontamination (test I).- The ETO decontamination test (test I) was carried out in accordance with reference 13 by preparing 43 samples in tensile jaws and placing them in the sterilizer (fig. 1) for processing. The chamber was initially evacuated to 84.7 kN/m^2 (25 in. Hg) and backfilled with water vapor to obtain a 40 percent relative humidity at 40° C (104° F) for a period of 1 hr. Next, the decontamination gas (12 percent ETO, 88 percent Freon-12) was released into the chamber until the concentration reached 500 mg/liter and produced a chamber pressure of 20.7 kN/m^2 (3 psig). After 24 hr, the chamber was evacuated for 15 min before venting to the atmosphere. A typical temperature-time cycle for decontamination is shown in figure 7(a). The exposed samples were then removed from the decontamination chamber and placed in the tensile apparatus of the vacuum chamber (fig. 3). This transfer took about an hour and was considered an in situ operation.

Dry heat sterilization (tests I and III).- Exposure of the Dacron samples to the environment of dry heat sterilization (tests I and III) was carried out in the 150-cubic-foot space vacuum facility. With the samples in the tensile apparatus, the vacuum chamber was evacuated by the roughing pump to a pressure of 84.7 kN/m^2 (25 in. Hg) and backfilled with dry nitrogen to a pressure of 27.1 kN/m^2 (8 in. Hg). The calrod heaters were switched on and the temperature increased to 125° C (257° F) during a 3-hr period. The temperature was maintained at 125° C (257° F) for 24.5 hr. The power was then switched off, and the temperature reduced to 22° C (72° F) during a 3-hr period with the aid of liquid nitrogen passing through the chamber liner. A typical sterilization cycle is graphically shown in figure 7(b).

Vacuum (tests I, III, and IV).- Vacuum for tests I, III, and IV was obtained by evacuating the chamber with the pumping equipment previously described. When a pressure of 1×10^{-6} torr (1 torr = 133.322 N/m^2) was reached, the first group of vacuum-exposed samples were tensile tested. Subsequent tensile tests of groups of 5 samples were made as a function of time during the allotted vacuum environment.

Martian atmosphere (test I).- The Martian atmosphere (test I) was simulated by increasing the pressure in the vacuum chamber containing the test samples to a pressure of 8 torr with a gas mixture that had a composition of 74.4 percent CO_2, 12.8 percent N_2, and 12.8 percent Ar. When a temperature of 24° C (75° F) was obtained, tensile testing was initiated.

Postvacuum (tests III and IV).- When studying the effect of vacuum, the chamber was vented to atmosphere and immediately 5 samples were tensile tested. Tensile testing was again repeated 24 hr later. Results obtained from this procedure were marked "postvacuum."

DATA REDUCTION

The record shown in figure 8 is typical of the records made for each uniaxial tensile test. From this record, the following mechanical properties of the Dacron were determined: maximum stress, elongation, total energy, and modulus.

Maximum stress was determined as the maximum force that could be applied per unit area at the time of rupture. Maximum stress was determined by extending a dashed line horizontally from the peak of the loading curve to the force scale. (See fig. 8.) For this investigation, 120 strands were equal to 2.54 cm (1 in.) in width, and the thickness of the sample was dimensionally insignificant. Therefore, the results were reported in newtons per centimeter (pounds per inch).

Elongation at maximum stress was determined by measuring the extension of the 7.62-cm (3 in.) sample at the point at which the applied force reached a maximum as represented by the dashed lines in figure 8. This measurement was made in centimeters (inches).

Total energy was determined by integrating the area beneath the stress-strain curve as shown by the shaded area of figure 8. Total energy was in joules (inch-pounds).

Modulus was determined as the ratio between stress and strain. Since the loading curve of Dacron exhibited two areas of linearity, an initial and final modulus was determined. Initial modulus was determined by extending a straight line from the origin along the loading curve. (See fig. 8.) From the point of tangency, the values of stress and strain were read from the record. From the ratio of stress to strain, the modulus was calculated in newtons per centimeter (pounds per inch). Similarly for final modulus, a line was constructed along the second linear portion of the loading curve and from the slope of the straight line the values of stress and strain were read. The ratio of these values gave the final modulus which was in newtons per centimeter (pounds per inch).

ACCURACY AND ERRORS

Each of the quantities measured during the test program was considered and the probable accuracies noted.

Tensile apparatus: Tensile testing 90 atmospheric control samples produced a deviation from 2.43 to 3.32, whereas 129 environmental samples gave a deviation from 0.22 to 4.33. As far as the real values produced by the two apparatus, both load cells were calibrated and had an accuracy of ±0.01 percent. Therefore, both pieces of equipment were assumed to be producing the same mechanical property response.

Mechanical properties measured are as follows:

Maximum stress: The tensile measurements for both the control and the environmentally exposed samples were performed with a load cell designed by NASA and Instron testing machine. The accuracy of the load-cell—recorder combination was ±0.5 percent of the indicated load. Indicated loads varied from 382.7 to 422.8 N (86 to 95 lb) which would indicate an error of ±0.75 to ±0.84 N/cm (±0.43 to ±0.48 lb/in.).

Elongation: The elongation of the test samples at maximum stress was measured from the stress-strain record with an engineer's scale that can be read to ±0.13 cm (±0.05 in.) This scale measurement when converted to elongation would result in an error of ±0.03 cm (±0.01 in.).

Total energy: The stress-strain record was used to determine the total energy values for each sample tested. Total energy was determined by integrating the area under the curve by use of a planimeter. The instrument was frequently calibrated, but with this instrument the greatest error would be operator error. All measurements were made by experienced personnel with a well calibrated instrument and estimated to be accurate to within ±0.5 percent. Since total energy varied between 4.34 to 9.88 J (38.4 to 87.4 in-lb) an error of 0.02 to 0.05 J (0.19 to 0.44 in-lb) would result from these measurements.

Modulus: Since the loading curve exhibited two areas of linearity, an initial and a final modulus were reported. Each modulus was determined by the slope of the straight-line portions of the stress-strain plot. An inherent inaccuracy in determining slopes resulted in an error of ±5 percent for initial modulus and ±10 percent for final modulus. Initial modulus varies between 1316 to 2139 N/cm (752 and 1222 lb/in.) which would indicate an error of ±67 to ±107 N/cm (±38 to ±61 lb/in.). Final modulus varied between 597 and 768 N/cm (341 and 439 lb/in.) which would indicate an error of ±60 and ±77 N/cm (±34 and ±44 lb/in.).

Mission environments: The accuracies of the test parameters for each of the environments are as follows:

Temperature: The temperature of the tensile samples while under ethylene oxide treatment, dry heat sterilization vacuum, and Martian atmosphere exposure were all measured by a copper-constantan thermocouple. The accuracy of the thermocouple near the samples was estimated to be within ±2.8° C (±5° F). The accuracy readout on the recorder was within ±1.1° C (±2° F).

Pressure: The ionization gage and controller used to record the pressures reported herein was calibrated for nitrogen gas with a flow-based orifice conductance system similar to that described in reference 14. The gage calibration showed a variation of ±6.9 percent at a pressure of 1×10^{-8} torr. The system used to calibrate this gage had an accuracy of ±5 percent. (See ref. 14.)

Humidity: The relative humidity of the control room where the atmospheric samples were stored and tested was within ±5 percent.

Time: The time for all tests was measured by an electric clock and was accurate to ±1 sec. Exposure time for the various environments ranged from hours to days. Therefore, an error of several seconds in time measurement was considered negligible.

RESULTS AND DISCUSSION

The results from the previously described test program are categorically divided into three parts; that is, the results obtained from the atmospheric controlled tests, the induced effects resulting from exposure to the various mission environments, and a statistical analysis of all the data.

Atmospheric Control Group

The results obtained from testing Dacron parachute material in an atmospheric environment of 24° C (75° F) and 45 percent relative humidity at intervals of 7, 14, and 21 days are shown in table 3. The mechanical properties – maximum stress, elongation at maximum stress, total energy, and initial and final modulus – were determined and are given for the sample tested at each time interval. The average values for each mechanical property are given together with their respective standard deviations. These data were then plotted as a function of time in figure 9 where the line connecting these three points was determined by the least-squares method.

Effects of Mission Environments

The results obtained from tensile testing a parachute material after exposure to the mission environments of ethylene oxide, dry heat sterilization, vacuum, and a simulated Martian atmosphere are given in table 4. A graphical representation of each of the mechanical properties was made comparing the test group to the control group, and these are discussed in detail.

Maximum stress: Maximum stress is plotted as a function of elapsed time in figure 10. At the top of the figure, the mission environments are shown in the sequence in which the samples were exposed and are scaled to correspond to the time scale at the bottom. The straight line represents the control group. The circle data points represent the average value for 5 samples tested after each environmental exposure with vertical bars indicating their respective standard deviation.

The results show that maximum stress was 156 N/cm (89.3 lb/in.) after exposure to all four mission environments. Compared to the atmospheric control value of 164 N/cm (93.7 lb/in.), this represents a change of -4.7 percent. However, maximum stress showed a variation from 166 N/cm (94.6 lb/in.) (2d day) after dry heat sterilization to 151 N/cm (86.5 lb/in.) (14th day) during the vacuum cycle. The sample-to-sample variation went from a low of 0.39 to a high of 4.33 percent. (See table 4.)

Elongation: Elongation at maximum stress is plotted as a function of time in figure 10. The results show that, at the completion of the mission exposures, elongation was 2.59 cm (1.02 in.). Comparing this value with the control group value of 2.87 cm (1.17 in.), a change of -12.8 percent results. Other measurements during the mission showed there was a variation of 2.45 cm (0.97 in.) (14th day) to 2.77 cm (1.09 in.) (16th day) which both occurred during the vacuum environment. The sample-to-sample variation for each tensile test was from 1.12 to 15.75 percent. (See table 4.)

Total energy: Total energy as shown in figure 10 is plotted as a function of time. The results from table 4 show that total energy was 6.48 J (57.32 in-lb) after exposure to all four mission environments. Compared with the control value of 7.8 J (69.40 in-lb), this amounted to a change of -17.4 percent. There was, however, a variation of 5.74 J (50.80 in-lb) (1st day) after ethylene oxide decontamination and 7.15 J (63.27 in-lb) (16th day) after exposure to the vacuum environment. For total energy, the sample-to-sample variation went from 4.16 to 19.74 percent. (See table 4.)

Modulus: Modulus, as previously defined, is divided into initial and final modulus and these are plotted as a function of time in figure 10. The control value for initial modulus was 1605 N/cm (917 lb/in.), whereas at the end of the mission exposure it was 1454 N/cm (831 lb/in.). This represents a change of -9.4 percent. During the course of the mission simulation, initial modulus varied between 1446 N/cm (826 lb/in.) (1st day) and 1580 N/cm (903 lb/in.) (3d day) with a sample-to-sample variation from 2.83 to 14.20 percent. (See table 4.)

Final modulus on the other hand showed a change of +0.8 percent when the control value of 637 N/cm (364 lb/in.) is compared with 644 N/cm (368 lb/in.) at the end of the mission exposure. The variation during the testing went from 667 N/cm (381 lb/in.) (2d day) to 637 N/cm (364 lb/in.) (10th day). The sample-to-sample variation went from 0.52 to 4.42 percent. (See table 4.)

Effects of Dry Heat Sterilization and Vacuum

This series of mechanical property determinations resulted from exposing the parachute material to dry heat sterilization followed by a period of vacuum. The mechanical properties resulting from the experimental program are given in table 5.

Plots of the mechanical properties as a function of time are shown in figure 11. On examining these plots it appears that for the mechanical properties of maximum stress, elongation at maximum stress, and total energy there was a gradual reduction in mechanical property values with time to the completion of the vacuum exposure. However, when the Dacron samples were reexposed to atmospheric pressure, there appeared to be a recovery approaching the control group values.

Effects of Vacuum

The effects that vacuum had on the mechanical properties are given in table 6. Plots of the mechanical properties as a function of elapsed time are shown in figure 12. Although these plots do not show any definite trend with time, the magnitude of the maximum induced changes compared with the control group are larger than resulted from any other environmental exposure.

Ethylene Oxide Decontamination

The single effect of ethylene oxide decontamination on the mechanical properties of Dacron is given in table 4. From these results, it appears that there was a reduction in mechanical properties caused by ethylene oxide, but the magnitude appears to be similar to that induced by exposure to the other mission environments.

Dry Heat Sterilization

The results from exposing Dacron to dry heat sterilization are given in table 5. From these results, it appears that dry heat sterilization has the least significant effect on Dacron of any of the four mission environments or their sequential combination.

The induced changes caused by exposing the Dacron parachute material to the combined effects of all four of the mission environments are given in table 7. These changes did not exceed -8 percent in maximum stress, -23.0 percent in elongation at maximum stress, -29 percent in total energy, -12 percent in initial modulus, and +9 percent in final modulus. In addition, each separate effect of these environments is shown in table 7.

Effects of Humidity

Although all the Dacron samples were stored under the controlled atmospheric environment of 45 percent relative humidity, Dacron fibers have the lowest water absorption capability of any of the man-made fibers. (See ref. 15.) There was no evidence that the loss of this small water content could be correlated to any induced changes in mechanical properties.

Vacuum Data

The vacuum histories for each of the three environmental tests are shown in figure 13, where pressure is plotted as a function of time. The pressure measurements shown have been corrected for ionization-gage error from calibration data furnished prior to the test program.

Effect of Sample Position

Although the samples were cut and marked from the bulk material as shown in figure 5, there was no detectable difference in mechanical properties noted by a difference in sample locations.

Statistical Analysis

The mechanical property data obtained from the test program were analyzed by statistical methods to determine their precision. The details of such an analysis are given in appendix B.

CONCLUSIONS

In view of the results obtained from this investigation, the following conclusions are made:

1. The mission environments of ethylene oxide decontamination, dry heat sterilization, vacuum, and a simulated Martian atmosphere induced a change in the mechanical properties of Dacron Type 55. These changes did not exceed -8 percent in maximum stress, -23.0 percent in elongation at maximum stress, -29 percent in total energy, -12 percent in initial modulus, and +9 percent in final modulus.

2. The results obtained from exposing Dacron parachute material to the various mission environments did not exhibit any definite trend with time up to 16 days.

3. The mission environment of vacuum induced the greatest single effect on the mechanical properties of Dacron Type 55. However, a trend of recovery occurred after exposure to the Martian atmosphere.

4. The effects of the various environments were not additive, and a determination of material effects for a complete mission must include the expected sequence of the mission environments.

Langley Research Center,
National Aeronautics and Space Administration,
Hampton, Va., April 27, 1971.

APPENDIX A

PROCEDURE FOR TENSILE SAMPLE PREPARATION

A jig was fabricated as shown in figure 14(a) to permit reproducible layout of the ASTM material samples in a set of tensile test jaws. The assembly was started by taking one-half of an upper and a lower jaw and placing them in the appropriate place in the jig. (See fig. 14(b).) Next, a 3.8- by 7.6-cm $\left(1\frac{1}{2}\text{ by 3 in.}\right)$ Dacron "spacer" was folded in half and placed on each half jaw so that 0.64 cm (1/4 in.) of the material extends over the face of the jaw in the direction of the applied load. Over this padding was placed the 2.5- by 25.4-cm (1 by 10 in.) Dacron test specimen, making sure that the "fill" of the material was parallel to the tensile jaw edges and that the excess length extended beyond the lower jaw. (See fig. 14(b).) Then, another piece of folded padding was placed over the test specimen as before, the other half of the upper jaw set in place, the cap screws put in the jaw, and the screws tightened by a torque wrench to 1.7 m-N (15 in-lb) by a diagonally opposite technique. (See fig. 14(c).) To the free end, a weighted clip $\left(\text{approximately 496 g }\left(17\frac{1}{2}\text{ oz}\right)\right)$ was added as shown in figure 14(d), so that proper alinement could be maintained through the remainder of the assembly. When this was done, the second folded padding, the lower jaw, and the cap screws were assembled in the same manner as previously described for the upper jaw. Next, the excess material was cut off (fig. 14(e)) and the finished assembly (fig. 14(f)) was then ready to be placed in the tensile test apparatus. (See fig. 3.)

APPENDIX B

STATISTICAL ANALYSIS

In order to give credence to the data, determining the number of samples to test in any textile mechanical property study is generally accomplished by statistical analysis. The ASTM recommendation of five tests (N = 5) was selected because this number applied to samples cut in the warpwise direction.

On completion of the tensile tests after exposure to the various mission environments, the next step was to determine the precision of the data to see if it met the requirements specified by ASTM. The ASTM specification calls for a precision within ±5 percent at a probability level of 90 percent. This precision was calculated by use of the following equations:

$$\bar{x} = \frac{1}{N} \sum_{i=1}^{N} x_i \tag{1}$$

$$s^2 = \frac{1}{N} \sum_{i=1}^{N} \left(x_i - \bar{x}\right)^2 \tag{2}$$

$$(\mu - \bar{x}) = \frac{t}{\sqrt{N - 1}} s \tag{3}$$

where

t	values as found from Student's t distribution
s	standard deviation
N	number of samples taken
x_i	value of individual sample
$\bar{x}$	mean value of N samples
μ	true mean of infinite number of samples

The precision of each breaking load data point associated with the environmental exposure studies is listed in tables 8, 9, and 10. The results show that, with a 90-percent probability, the breaking loads had a precision between 0.2 and 4.1 of the true mean.

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TABLE 1.- DACRON FABRIC SPECIFICATION

Lot no.	Roll no.	Width (min.), cm (in.)	Ends (min.), cm (in.)	Picks (min.)	Tenacity (min.)		Elongation (min.), percent		Porosity, $m^3/min/m^2$ $(ft^3/min/ft^2)$	Trapezoid tears, N (lb)		Shrinkage at 300° F, percent, after –			
												8 hr		16 hr	
					Warp	Fill	Warp	Fill		Warp	Fill	Warp	Fill	Warp	Fill
1430	1	113 (44.5)	284 (112)	84	85	58	33	39	53 (175)	133 (30)	53 (12.0)	0.5	0.0	0.6	0.0
	2	113 (44.5)	284 (112)	84	85	59	33	39	49 (161)	111 (25)	58 (13.0)				
	3	113 (44.5)	284 (112)	84	85	60	33	39	42 (136)	151 (34)	59 (13.2)				
	4	113 (44.5)	284 (112)	84	85	61	33	39	53 (173)	111 (25)	49 (11.0)				

TABLE 2.- TEST PROGRAM

Test	Mission environment	Temperature		Pressure, torr	Gas analysis, percent
		°C	°F		
I	Ethylene oxide	40	104	760	12 ETO 88 Freon-12
	Dry heat sterilization	125	257	570	100 dry N_2
	Vacuum	24	75	1×10^{-6} to 5×10^{-8}	0
	Martian atmosphere	24	75	8	74.4 CO_2 12.8 N_2 12.8 Ar
II	Atmosphere	24	75	760	45 relative humidity
III	Dry heat sterilization	125	257	570	100 dry N_2
	Vacuum	24	75	1×10^{-6} to 5×10^{-8}	0
IV	Vacuum	24	75	1×10^{-6} to 1×10^{-8}	0

TABLE 3.- TENSILE TEST OF DACRON PARACHUTE MATERIAL IN AN ATMOSPHERIC ENVIRONMENT OF 24° C (75° F) AND 45 PERCENT RELATIVE HUMIDITY

(a) Exposure time, 7 days

	Maximum stress		Elongation at maximum stress		Total energy		Initial modulus		Final modulus	
	N/cm	lb/in.	cm	in.	J	in-lb	N/cm	lb/in.	N/cm	lb/in.
	170	97.0	3.20	1.26	8.72	77.2	2048	1170	611	349
	168	96.0	3.25	1.28	8.97	79.4	1474	842	602	344
	162	92.5	2.69	1.06	6.90	61.1	1356	775	620	354
	170	97.0	3.25	1.28	9.02	79.8	1720	983	618	353
	167	95.5	3.05	1.20	8.14	72.0	1974	1128	630	360
	168	96.0	2.90	1.14	7.83	69.3	1755	1003	679	388
	167	95.5	3.05	1.20	8.07	71.4	1398	799	768	439
	166	95.0	2.95	1.16	7.65	67.7	1491	852	614	351
	156	89.0	2.39	0.94	5.49	48.6	1398	799	597	341
	145	83.0	2.18	0.86	4.95	43.8	1404	802	653	373
	163	93.0	2.69	1.06	6.63	58.7	1316	752	658	376
	161	92.0	2.74	1.08	6.71	59.4	1810	1034	602	344
	170	97.0	3.00	1.18	8.07	71.4	1864	1065	653	373
	166	95.0	3.05	1.20	8.33	73.7	1720	983	639	365
	170	97.0	3.35	1.32	9.33	82.6	1316	752	627	358
	168	96.0	2.90	1.14	7.75	68.6	1619	925	653	373
	165	94.5	3.15	1.24	8.38	74.2	1974	1128	611	349
	166	95.0	3.05	1.20	8.28	73.3	1404	802	613	350
	165	94.5	3.00	1.18	7.91	70.0	1503	859	639	365
	168	96.0	3.35	1.32	9.15	81.0	1579	902	604	345
	169	96.5	3.25	1.28	8.97	79.4	1974	1128	606	346
	150	85.5	2.08	0.82	4.50	39.8	1645	940	653	373
	161	92.0	3.25	1.28	8.45	74.8	1755	1003	602	344
	165	94.0	3.05	1.20	8.10	71.7	1491	852	628	359
	165	94.5	3.25	1.28	8.61	76.2	1755	1003	621	355
	164	93.5	3.10	1.22	8.15	72.1	1316	752	609	348
	169	96.5	3.20	1.26	8.79	77.8	1619	925	648	370
	160	91.5	2.84	1.12	7.25	64.2	1491	852	613	350
	165	94.5	3.10	1.22	8.08	71.5	1316	752	630	360
Average	165	94.0	2.97	1.17	7.83	69.1	1602	916	632	361
Standard deviation	5.81	3.32	0.33	0.13	1.21	10.7	224	128.0	33	19

TABLE 3.- TENSILE TEST OF DACRON PARACHUTE MATERIAL IN AN ATMOSPHERIC ENVIRONMENT OF 24° C (75° F) AND 45 PERCENT RELATIVE HUMIDITY – Continued

(b) Exposure time, 14 days

	Maximum stress		Elongation at maximum stress		Total energy		Initial modulus		Final modulus	
	N/cm	lb/in.	cm	in.	J	in-lb	N/cm	lb/in.	N/cm	lb/in.
	161	92.0	3.05	1.20	7.82	69.2	1619	925	625	357
	165	94.0	3.30	1.30	8.89	78.7	1404	802	611	349
	165	94.0	3.25	1.28	8.66	76.6	1619	925	611	349
	163	93.0	3.05	1.20	7.99	70.7	1404	802	628	359
	162	92.5	3.05	1.20	7.90	69.9	1404	802	621	355
	160	91.5	3.00	1.18	7.60	67.3	1535	877	618	353
	164	93.5	3.15	1.24	8.41	74.4	1645	940	634	362
	163	93.0	3.00	1.18	7.56	66.9	1316	752	630	360
	167	95.5	3.35	1.32	9.03	79.9	1503	859	599	342
	168	96.0	3.25	1.28	9.15	81.0	1491	852	630	360
	166	95.0	3.10	1.22	8.34	73.8	1755	1003	621	355
	168	96.0	3.40	1.34	9.21	81.5	1755	1003	621	355
	165	94.5	3.25	1.28	8.49	75.1	1619	925	611	349
	165	94.0	3.20	1.26	8.54	75.6	1503	859	611	349
	165	94.5	3.00	1.18	8.14	72.0	1755	1003	621	355
	166	95.0	3.15	1.24	8.57	75.8	1619	925	630	360
	166	95.0	3.20	1.26	8.72	77.2	1645	940	653	373
	162	92.5	3.05	1.20	7.89	69.8	1645	940	625	357
	162	92.5	3.00	1.18	7.86	69.6	1503	859	648	370
	160	91.5	2.90	1.14	7.30	64.6	1843	1053	611	349
	161	92.0	2.84	1.12	7.23	64.0	2139	1222	625	357
	165	94.5	3.05	1.20	8.11	71.8	1491	852	679	388
	154	88.0	2.44	0.96	5.63	49.8	1519	868	604	345
	166	95.0	3.10	1.22	8.58	75.9	1755	1003	690	394
	165	94.5	3.05	1.20	8.16	72.2	1412	806	639	365
	162	92.5	2.79	1.10	7.07	62.6	1619	925	653	373
	147	84.0	2.34	0.92	4.34	38.4	1535	877	618	353
	162	92.5	2.95	1.16	7.63	67.5	1383	790	630	360
	162	92.5	2.84	1.12	7.32	64.8	1598	913	630	360
Average	163	93.1	3.03	1.19	7.93	70.2	1587	907	628	359
Standard deviation	4.25	2.43	0.23	0.09	1.02	9.0	168	96	21	12

TABLE 3.- TENSILE TEST OF DACRON PARACHUTE MATERIAL IN AN ATMOSPHERIC ENVIRONMENT OF 24° C (75° F) AND 45 PERCENT RELATIVE HUMIDITY – Concluded

(c) Exposure time, 21 days

	Maximum stress		Elongation at maximum stress		Total energy		Initial modulus		Final modulus	
	N/cm	lb/in.	cm	in.	J	in-lb	N/cm	lb/in.	N/cm	lb/in.
	168	96.0	3.15	1.24	8.48	75.0	1598	913	630	360
	165	94.5	3.00	1.18	7.79	68.9	1404	802	630	360
	172	98.5	3.05	1.20	8.42	74.5	1755	1003	672	384
	165	94.0	2.90	1.14	7.45	65.9	1645	940	634	362
	170	97.0	3.20	1.26	8.88	78.6	1974	1128	669	382
	161	92.0	2.39	0.94	5.91	52.3	1645	940	679	388
	171	97.5	2.95	1.16	7.90	69.9	1645	940	679	388
	165	94.0	3.10	1.22	8.16	72.2	1645	940	630	360
	168	96.0	2.95	1.16	8.00	70.8	1843	1053	663	379
	165	94.0	2.79	1.10	7.15	63.3	1755	1003	670	383
	172	98.5	3.15	1.24	8.81	78.0	1645	940	658	376
	165	94.0	3.05	1.20	8.07	71.4	1974	1128	648	370
	159	91.0	2.44	0.96	5.70	50.4	1556	889	663	379
	167	95.5	3.20	1.26	8.76	77.5	1710	977	634	362
	168	96.0	3.45	1.36	9.88	87.4	1535	877	630	360
	168	96.0	3.15	1.24	8.71	77.1	1843	1053	668	382
	168	96.0	2.95	1.16	7.89	69.8	1404	802	698	399
	167	95.5	3.10	1.22	8.34	73.8	1398	799	688	393
	169	96.5	3.00	1.18	8.80	77.9	1974	1128	674	385
	153	87.5	2.34	0.92	5.19	45.9	1404	802	639	365
	160	91.5	2.64	1.04	6.47	57.3	1598	913	644	368
	168	96.0	3.15	1.24	8.45	74.8	1491	852	630	360
	171	97.5	3.35	1.32	9.45	83.6	1535	877	663	379
	167	95.5	3.20	1.26	8.59	76.0	1535	877	639	365
	170	97.0	2.95	1.16	7.98	70.6	1645	940	688	393
	157	89.5	2.49	0.98	5.76	51.0	1398	799	648	370
	158	90.0	2.39	0.94	5.56	49.2	1579	902	658	376
	164	93.5	3.20	1.26	8.59	76.0	1645	940	648	370
	167	95.5	2.79	1.10	7.23	64.0	1316	752	695	397
Average	165	94.6	2.94	1.16	7.80	69.1	1624	928	657	375
Standard deviation	4.81	2.75	0.30	0.12	1.22	10.80	179	102	21	12

TABLE 4.- TENSILE TEST OF DACRON PARACHUTE MATERIAL AFTER EXPOSURE TO ETHYLENE OXIDE, DRY HEAT STERILIZATION, VACUUM, AND SIMULATED MARTIAN ATMOSPHERE

Time, day	Mission environment	Maximum stress			Elongation at maximum stress[a]			Total energy			Initial modulus			Final modulus		
		N/cm	lb/in.	Percent variation	cm	in.	Percent variation	J	in-lb	Percent variation	N/cm	lb/in.	Percent variation	N/cm	lb/in.	Percent variation
1	ETO	156	88.9	4.33	2.48	0.98	15.75	5.74	50.80	19.74	1446	826	10.35	663	379	4.42
2	DHS	166	94.6	1.40	2.60	1.02	14.14	6.74	59.66	15.19	1489	851	7.45	667	381	2.28
3	VAC	157	89.7	0.52	2.68	1.06	10.78	6.73	59.57	5.15	1580	903	2.83	656	375	2.76
6	VAC	158	90.0	0.39	2.64	1.04	2.92	6.64	58.76	16.51	1545	883	14.20	648	370	0.52
10	VAC	152	86.9	3.69	2.52	0.99	12.53	6.13	54.21	19.61	1572	898	4.21	637	364	1.07
14	VAC	151	86.5	2.48	2.45	0.97	10.57	5.79	51.25	14.71	1509	862	5.02	658	376	3.37
16	VAC	161	92.1	0.59	2.77	1.09	3.03	7.15	63.27	4.16	1579	902	7.65	660	377	4.02
16	MA	156	89.3	3.00	2.68	1.06	7.01	6.85	60.59	12.08	1516	866	11.65	663	379	2.58
17	MA	156	89.3	3.00	2.58	1.02	1.12	6.48	57.32	17.25	1454	831	3.06	644	368	2.41

[a]Gage length, 7.62 cm (3 in.).

TABLE 5.- TENSILE TEST OF DACRON PARACHUTE MATERIAL AFTER EXPOSURE TO DRY HEAT STERILIZATION AND VACUUM ENVIRONMENTS

Time, day	Mission environment	Maximum stress			Elongation at maximum stress[a]			Total energy			Initial modulus			Final modulus		
		N/cm	lb/in.	Percent variation	cm	in.	Percent variation	J	in-lb	Percent variation	N/cm	lb/in.	Percent variation	N/cm	lb/in.	Percent variation
1	DHS	161	91.9	0.63	2.80	1.10	2.08	7.33	64.83	2.81	1470	840	7.09	644	368	2.69
2	VAC	159	91.1	0.22	2.81	1.11	2.44	7.23	64.01	3.31	1547	884	10.34	637	364	3.25
3	VAC	158	90.3	0.44	2.82	1.11	2.61	7.26	64.22	3.51	1519	868	10.50	642	367	1.10
6	VAC	156	89.2	0.27	2.76	1.09	2.21	6.98	61.73	2.01	1622	927	9.25	630	360	4.39
9	VAC	156	88.9	4.16	2.81	1.11	4.71	6.32	55.90	26.58	1454	831	8.94	653	373	3.63
12	VAC	153	87.4	3.82	2.71	1.07	14.54	6.00	53.14	31.87	1607	918	11.42	656	375	1.61
14	VAC	152	86.7	3.78	2.40	0.94	14.83	5.82	51.49	20.55	1495	854	10.06	646	369	2.49
19	PV	161	92.0	2.97	2.79	1.10	9.54	7.32	64.80	13.78	1467	838	6.49	656	375	1.68
20	PV	159	90.7	3.66	2.79	1.10	8.90	7.09	62.72	13.86	1456	832	2.88	651	372	3.23

[a]Gage length, 7.62 cm (3 in.).

TABLE 6.- TENSILE TEST OF DACRON PARACHUTE MATERIAL AFTER EXPOSURE TO VACUUM

Time, day	Mission environment	Maximum stress			Elongation at maximum stress[a]			Total energy			Initial modulus			Final modulus		
		N/cm	lb/in.	Percent variation	cm	in.	Percent variation	J	in-lb	Percent variation	N/cm	lb/in.	Percent variation	N/cm	lb/in.	Percent variation
1	VAC	154	87.9	2.91	2.45	0.97	8.29	5.66	50.09	45.89	1472	841	11.63	676	386	3.30
4	VAC	156	89.1	3.02	2.30	0.90	22.90	5.53	48.98	33.75	1612	921	12.94	697	398	4.39
8	VAC	162	92.3	0.51	2.64	1.04	3.17	6.74	59.66	5.51	1594	911	4.54	679	388	2.69
13	VAC	160	91.3	3.06	2.61	1.03	10.43	6.46	57.16	15.54	1603	916	10.07	686	392	2.01
19	VAC	158	90.4	0.46	2.53	1.00	2.21	6.22	55.03	4.19	1421	812	6.33	691	395	3.02
25	VAC	160	91.6	2.86	2.52	0.99	10.97	6.16	54.47	16.41	1680	960	7.74	660	377	3.28
32	VAC	158	90.5	2.87	2.59	1.02	10.58	6.47	57.25	15.24	1524	872	7.80	674	385	0.71
32	PV	158	90.2	3.02	2.55	1.00	11.65	6.21	54.96	16.84	1526	871	10.40	683	390	4.14
33	PV	162	92.3	0.47	2.77	1.09	1.56	7.09	62.75	3.12	1601	915	7.31	670	383	2.09

[a]Gage length, 7.62 cm (3 in.).

TABLE 7.- EFFECTS OF MISSION ENVIRONMENTS ON THE MECHANICAL PROPERTIES OF DACRON PARACHUTE MATERIAL

Test	Environment	Induced change, percent				
		Maximum stress	Elongation at maximum stress	Total energy	Modulus	
					Initial	Final
I	ETO	-5.2	-16.2	-12.4	-9.9	+4.1
	ETO + DHS	0	-9.4	-14.0	-7.2	+4.5
	ETO + DHS + VAC	-7.7	-18.0	-8.8	-6.0	0
	ETO + DHS + VAC + MA	-4.7	-12.8	-17.4	-9.4	+0.8
III	DHS	-1.9	-6.0	-6.6	-8.4	+1.1
	DHS + VAC	-7.5	-19.7	-11.4	-9.4	-1.1
	DHS + VAC + PV	-3.2	-6.0	-9.6	-9.3	+2.2
IV	VAC	-6.2	-23.0	-29.4	-11.5	+9.3
	VAC + PV	-3.7	-14.5	-20.7	-5.0	+6.9

TABLE 8.- STATISTICAL ANALYSIS OF MAXIMUM STRESS AFTER EXPOSURE TO ETO, DHS, VACUUM, AND MARTIAN ATMOSPHERE

Time, day	Environment	No. of samples	Mean maximum stress, $\bar{x}$		Standard deviation, s	Precision with 90-percent probability, $\mu - \bar{x}$	
			N/cm	lb/in.		N/cm	lb/in.
1	ETO	5	155.6	88.9	4.3	7.2	4.1
2	DHS	5	165.6	94.6	1.4	2.3	1.3
3	VAC	5	157.0	89.7	0.5	0.9	0.5
6	VAC	5	157.5	90.0	0.4	0.7	0.4
10	VAC	5	152.1	86.9	3.7	6.1	3.5
14	VAC	5	151.4	86.5	2.5	4.2	2.4
16	VAC	5	161.2	92.1	0.6	1.1	0.6
16	MA	5	156.3	89.3	3.0	5.1	2.9
17	MA	5	156.3	89.3	3.0	5.1	2.9

TABLE 9.- STATISTICAL ANALYSIS OF MAXIMUM STRESS AFTER EXPOSURE TO DHS AND VACUUM ENVIRONMENTS

Time, day	Environment	No. of samples	Mean maximum stress, $\bar{x}$		Standard deviation, s	Precision with 90-percent probability, $\mu - \bar{x}$	
			N/cm	lb/in.		N/cm	lb/in.
1	DHS	5	160.8	91.9	0.6	1.1	0.6
2	VAC	5	159.4	91.1	0.2	0.4	0.2
3	VAC	5	158.0	90.3	0.4	0.7	0.4
6	VAC	5	156.1	89.2	0.3	0.5	0.3
9	VAC	5	155.6	88.9	4.2	7.0	4.0
12	VAC	5	153.0	87.4	3.8	6.3	3.6
14	VAC	5	151.7	86.7	3.8	6.3	3.6
19	PV	5	161.0	92.0	3.0	5.1	2.9
20	PV	5	158.7	90.7	3.7	6.1	3.5

TABLE 10.- STATISTICAL ANALYSIS OF MAXIMUM STRESS AFTER EXPOSURE TO A VACUUM ENVIRONMENT

Time, day	Environment	No. of samples	Mean maximum stress, $\bar{x}$		Standard deviation, s	Precision with 90-percent probability, $\mu - \bar{x}$	
			N/cm	lb/in.		N/cm	lb/in.
1	VAC	5	153.8	87.9	2.9	4.9	2.8
4	VAC	5	155.9	89.1	3.0	5.1	2.9
8	VAC	5	161.5	92.3	0.5	0.9	0.5
13	VAC	5	159.8	91.3	3.1	5.1	2.9
19	VAC	5	158.2	90.4	0.5	0.9	0.5
25	VAC	5	160.3	91.6	2.9	4.9	2.8
32	VAC	5	158.4	90.5	2.9	4.9	2.8
32	PV	5	157.9	90.2	3.0	5.1	2.9
33	PV	5	161.5	92.3	0.5	0.9	0.5

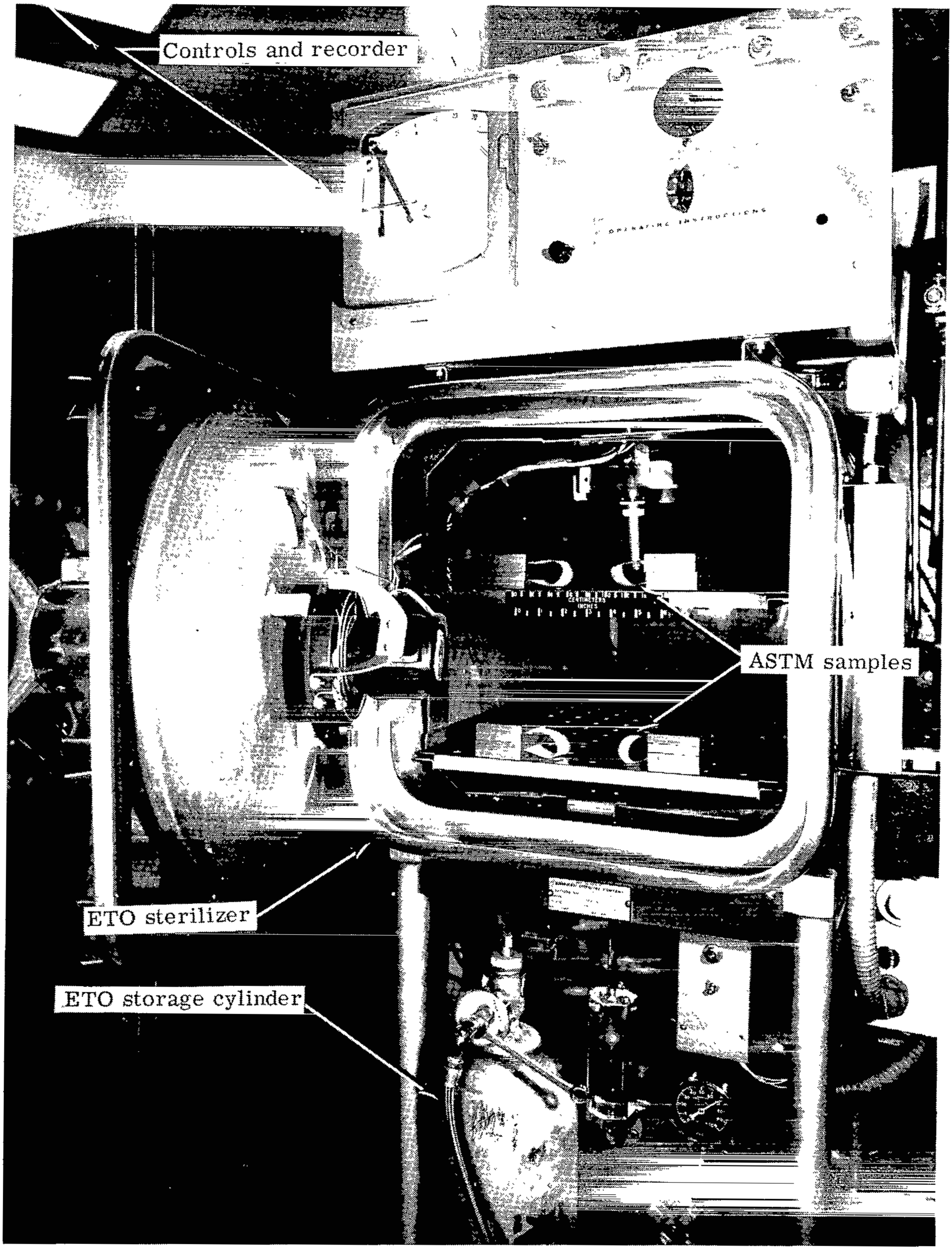

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Figure 1.- Ethylene oxide decontamination apparatus.

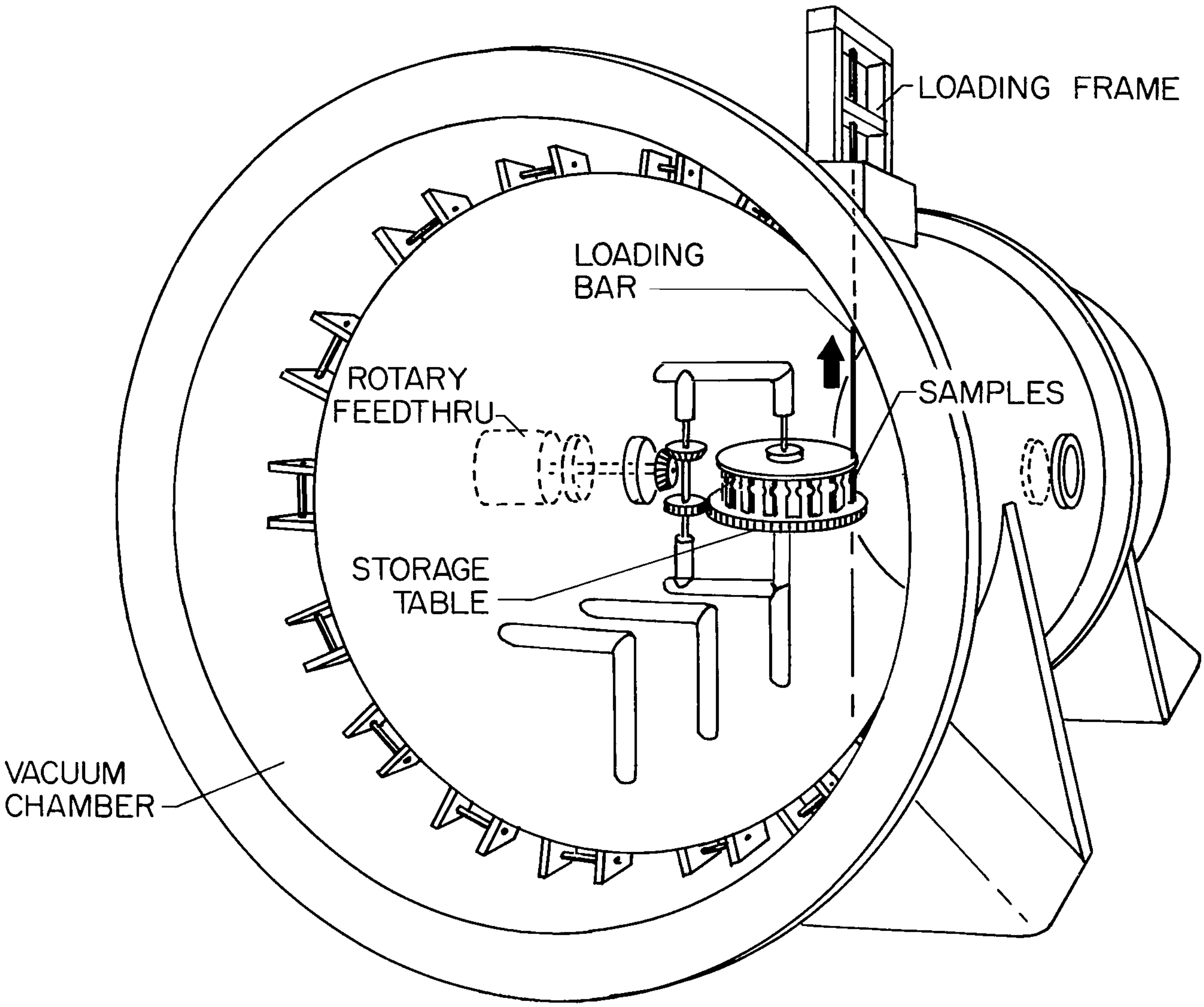

Figure 2.- Schematic diagram of the vacuum facility with tensile test apparatus.

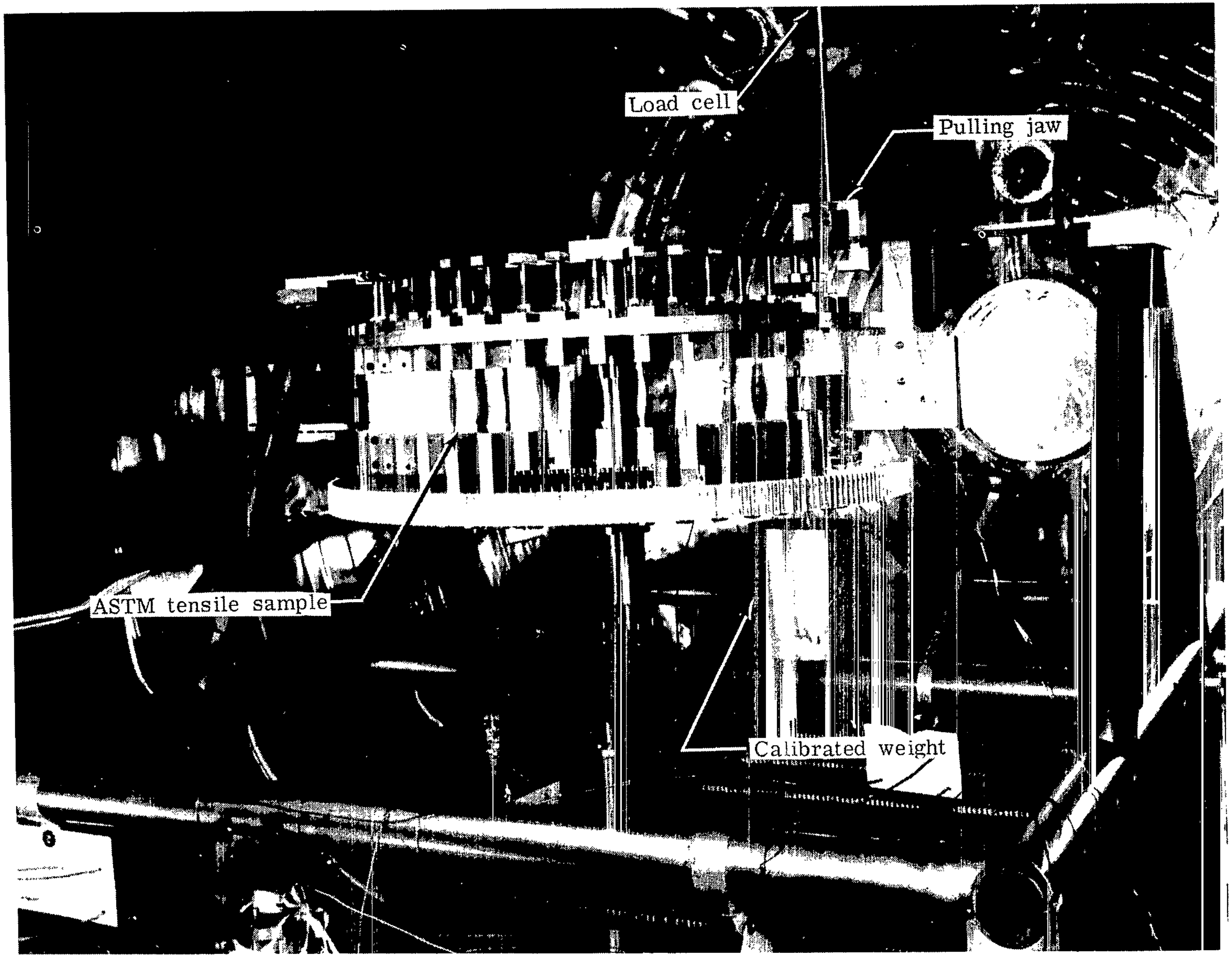

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Figure 3.- Langley 150-cubic-foot space vacuum facility with the tensile test apparatus.

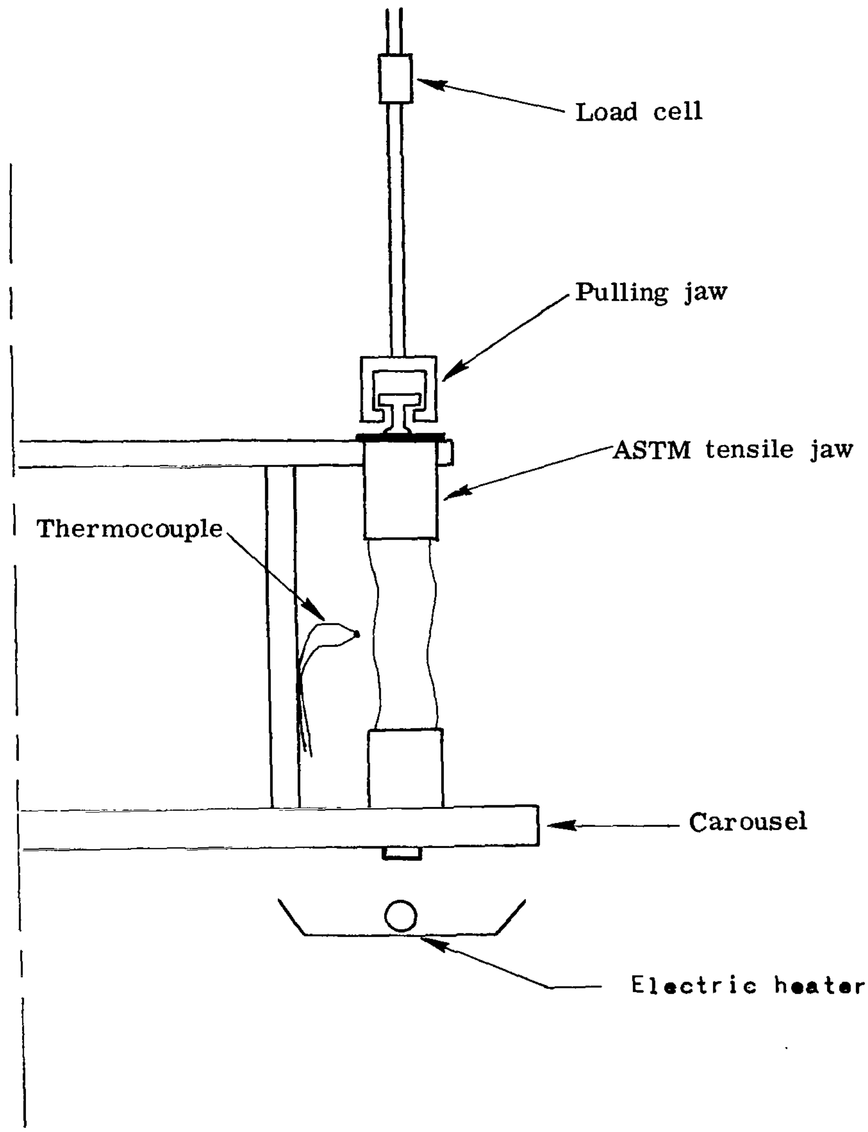


Figure 4.- Schematic diagram of the vacuum facility dry heat sterilization apparatus.

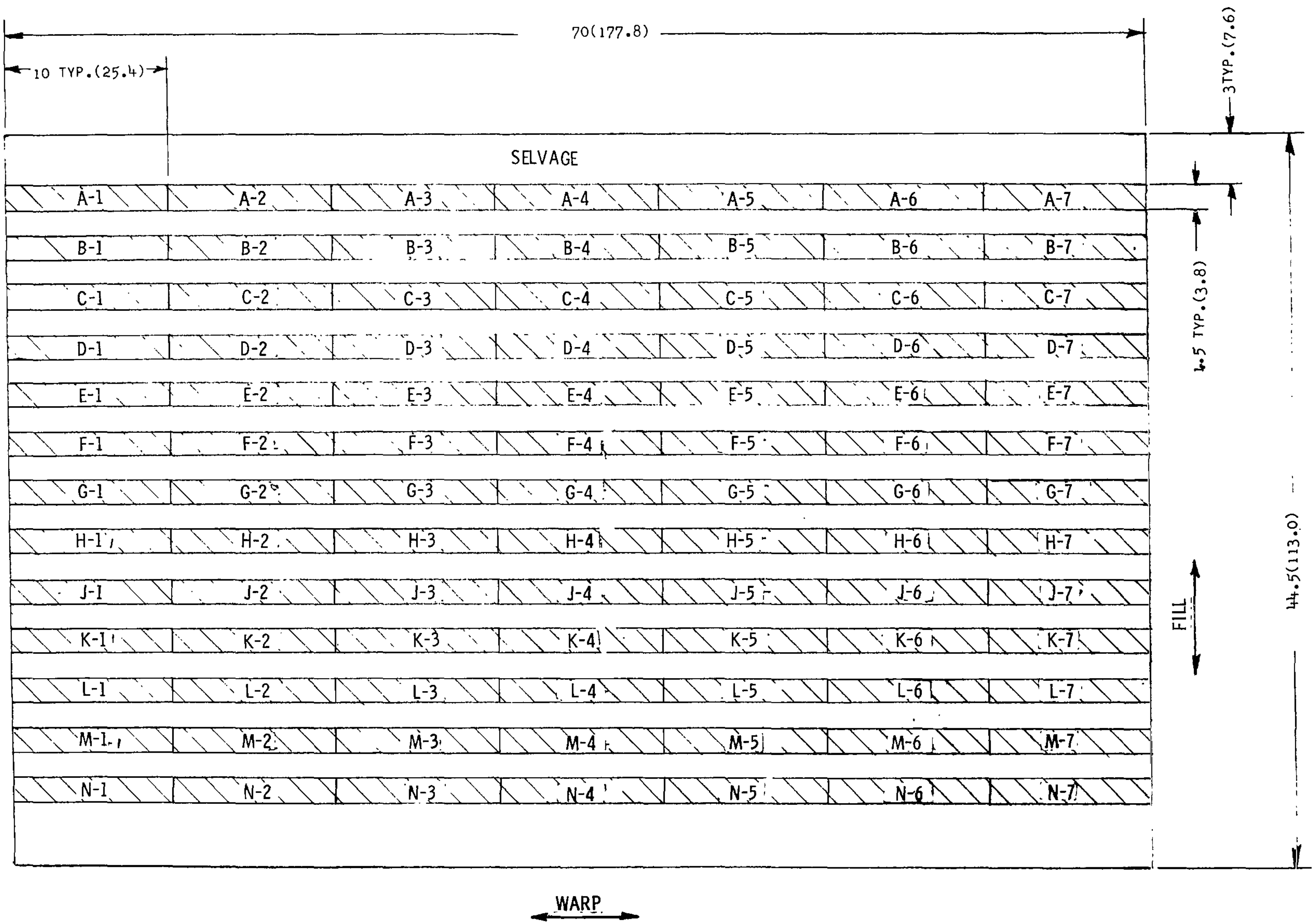


Figure 5.- Sample layout on bulk Dacron parachute material. All dimensions are in in. (cm).

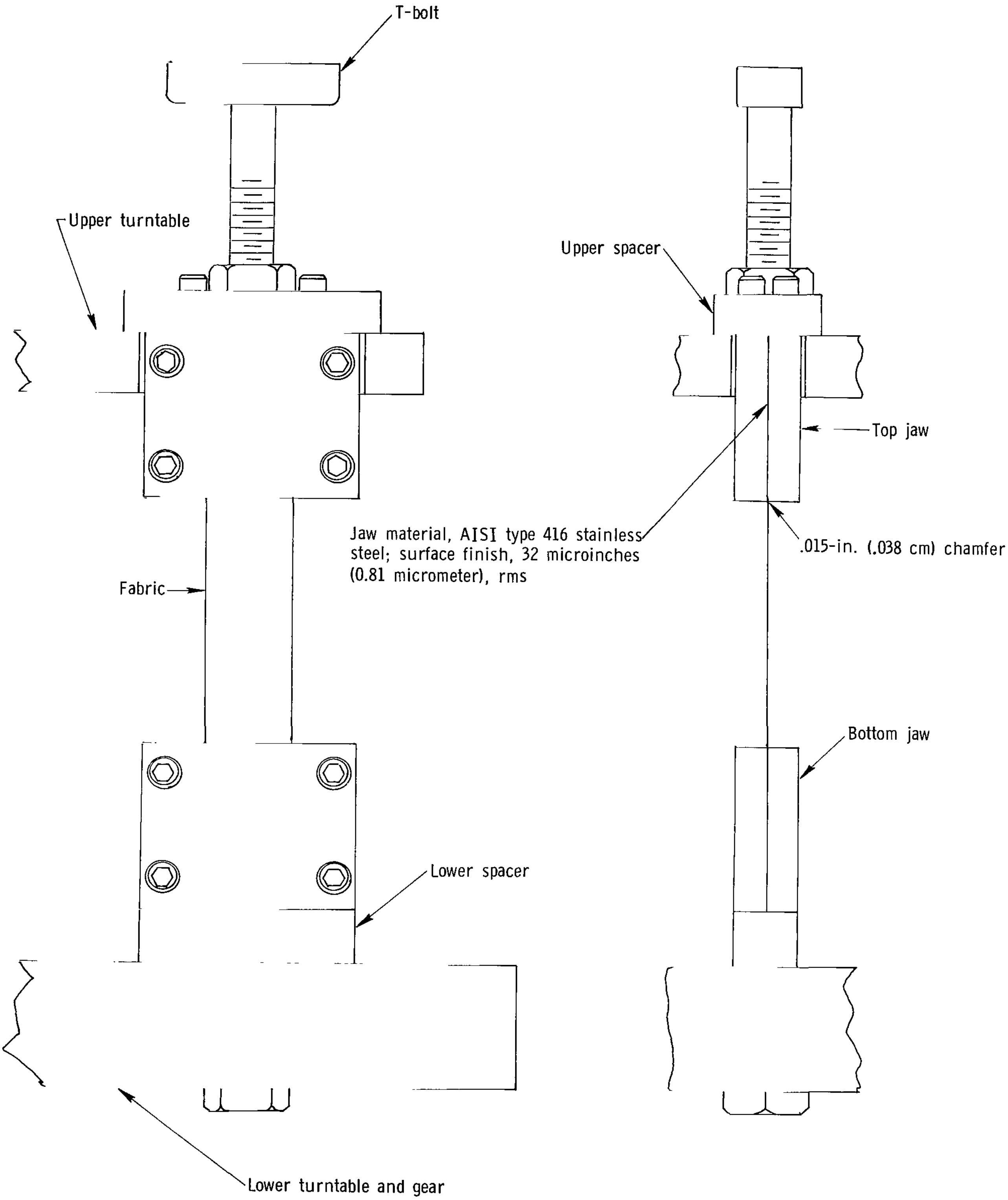
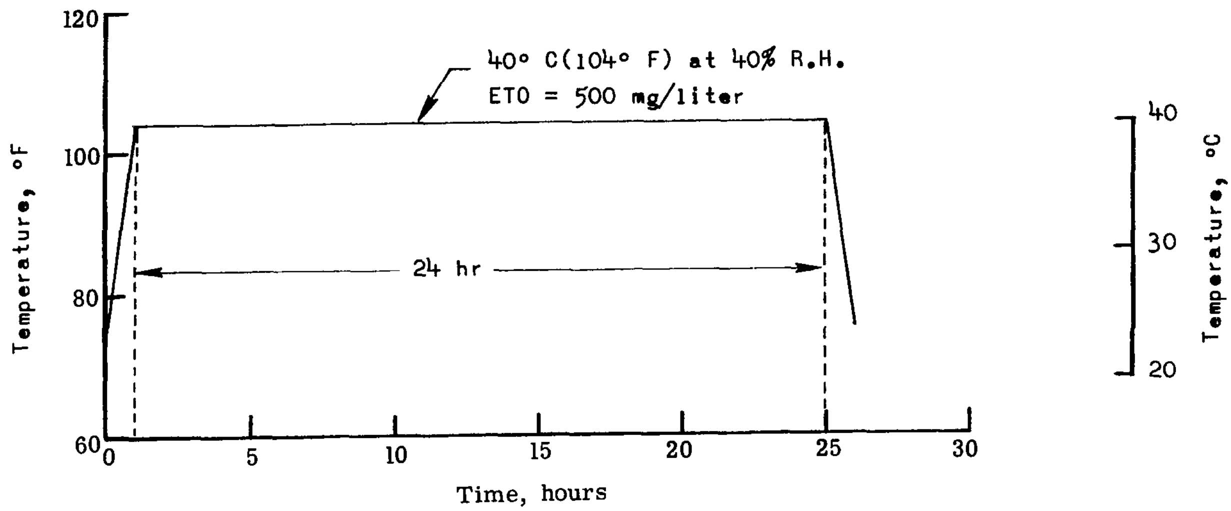
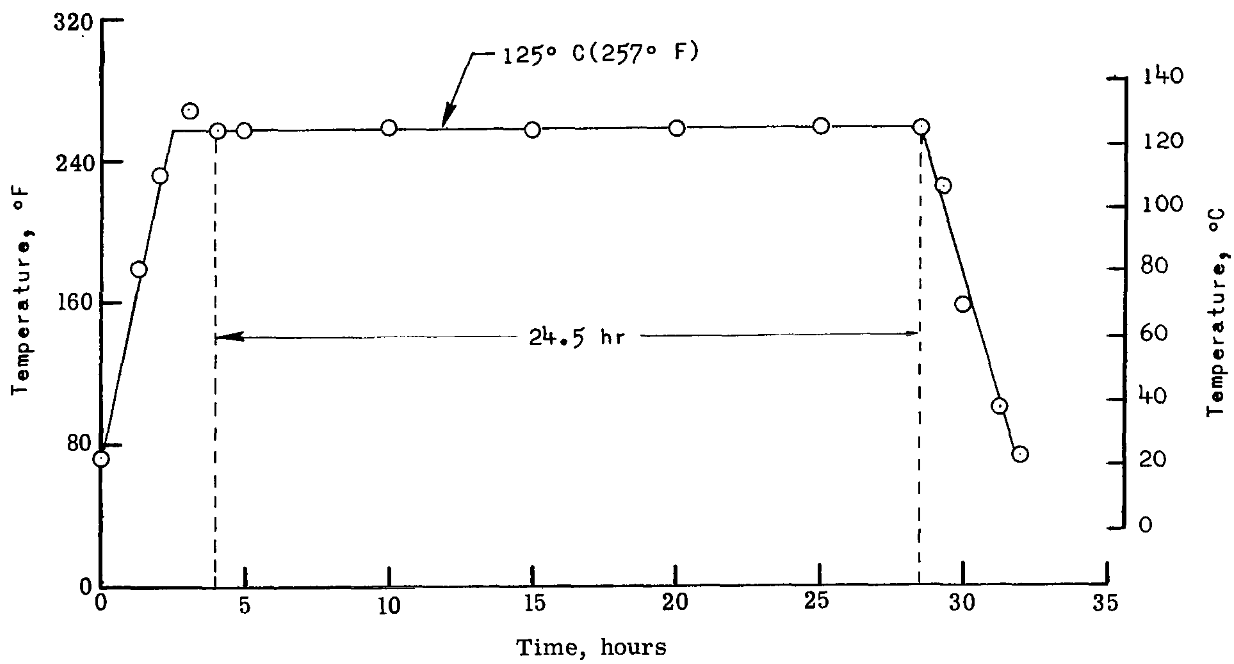


Figure 6.- ASTM tensile jaw design for fabrics.



(a) ETO decontamination cycle.



(b) Dry heat sterilization cycle.

Figure 7.- Procedures for ETO decontamination and dry heat sterilization.

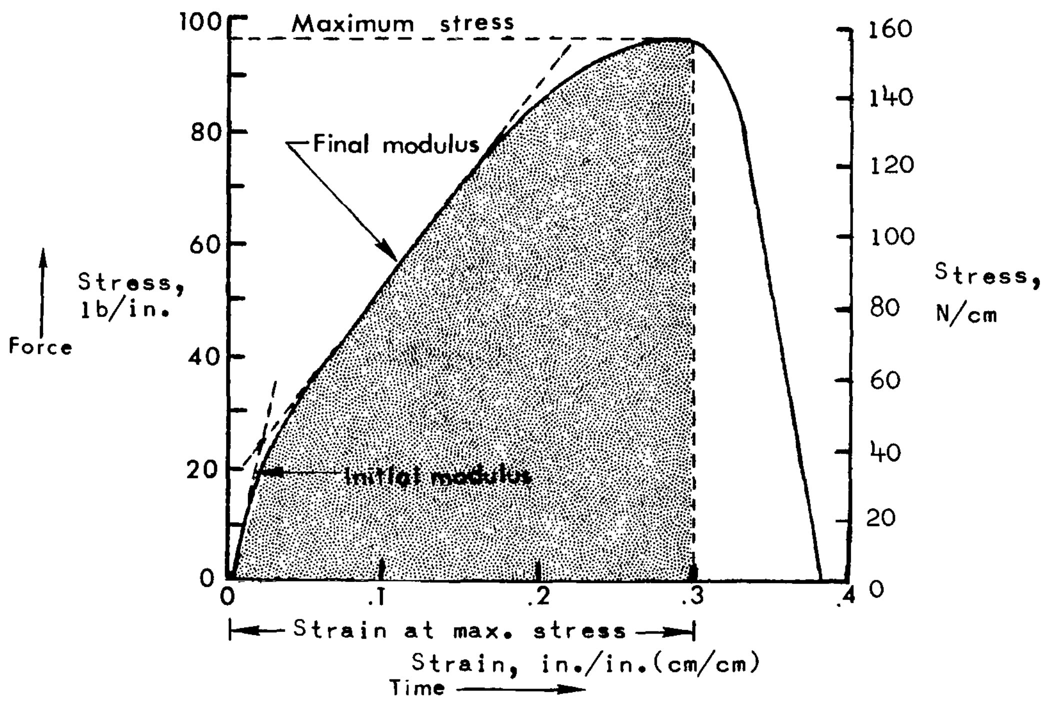


Figure 8.- Typical stress-strain record.

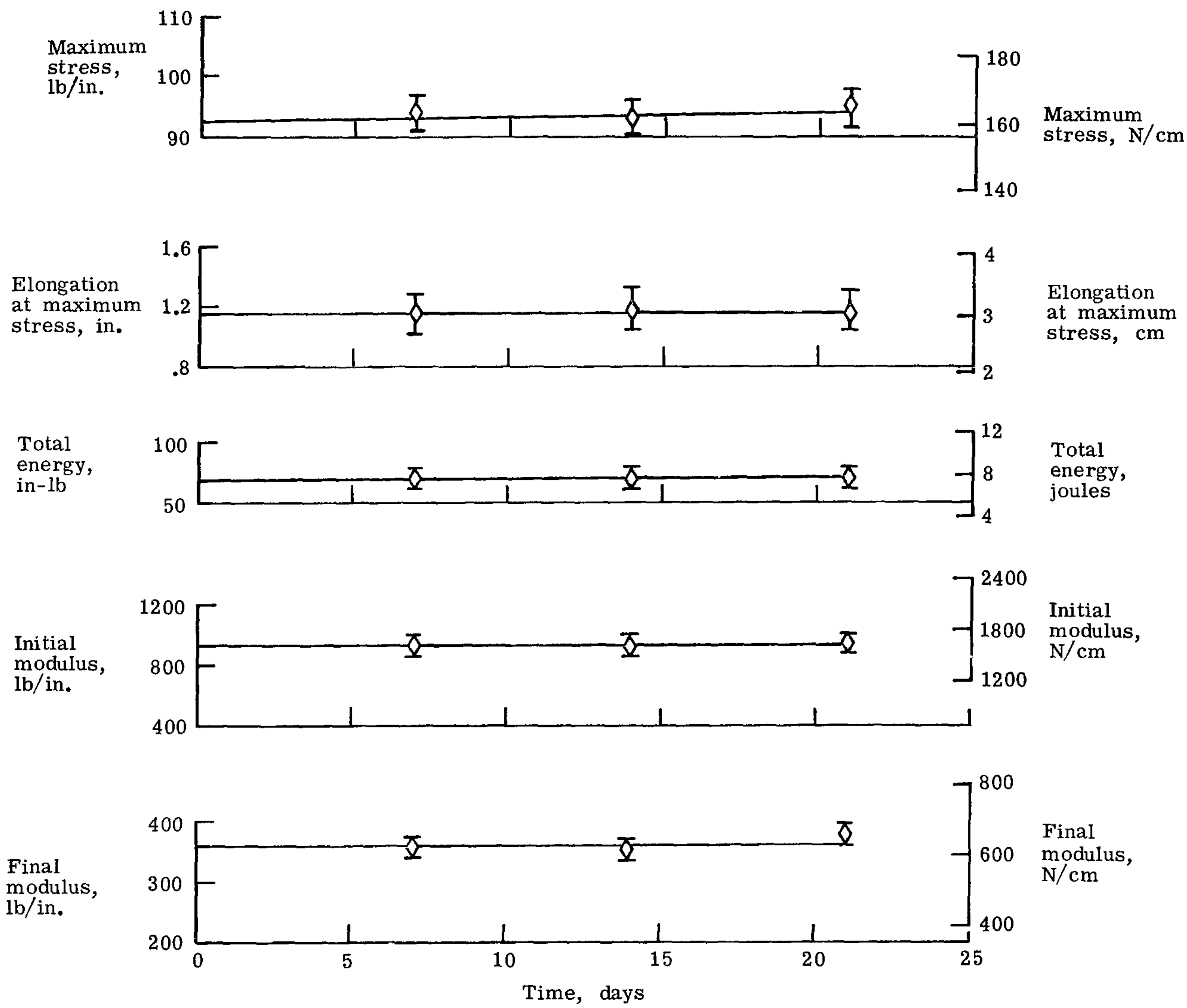


Figure 9.- Variation in mechanical properties with time after exposure to an atmospheric environment of 24° C (75° F) and 45 percent relative humidity.

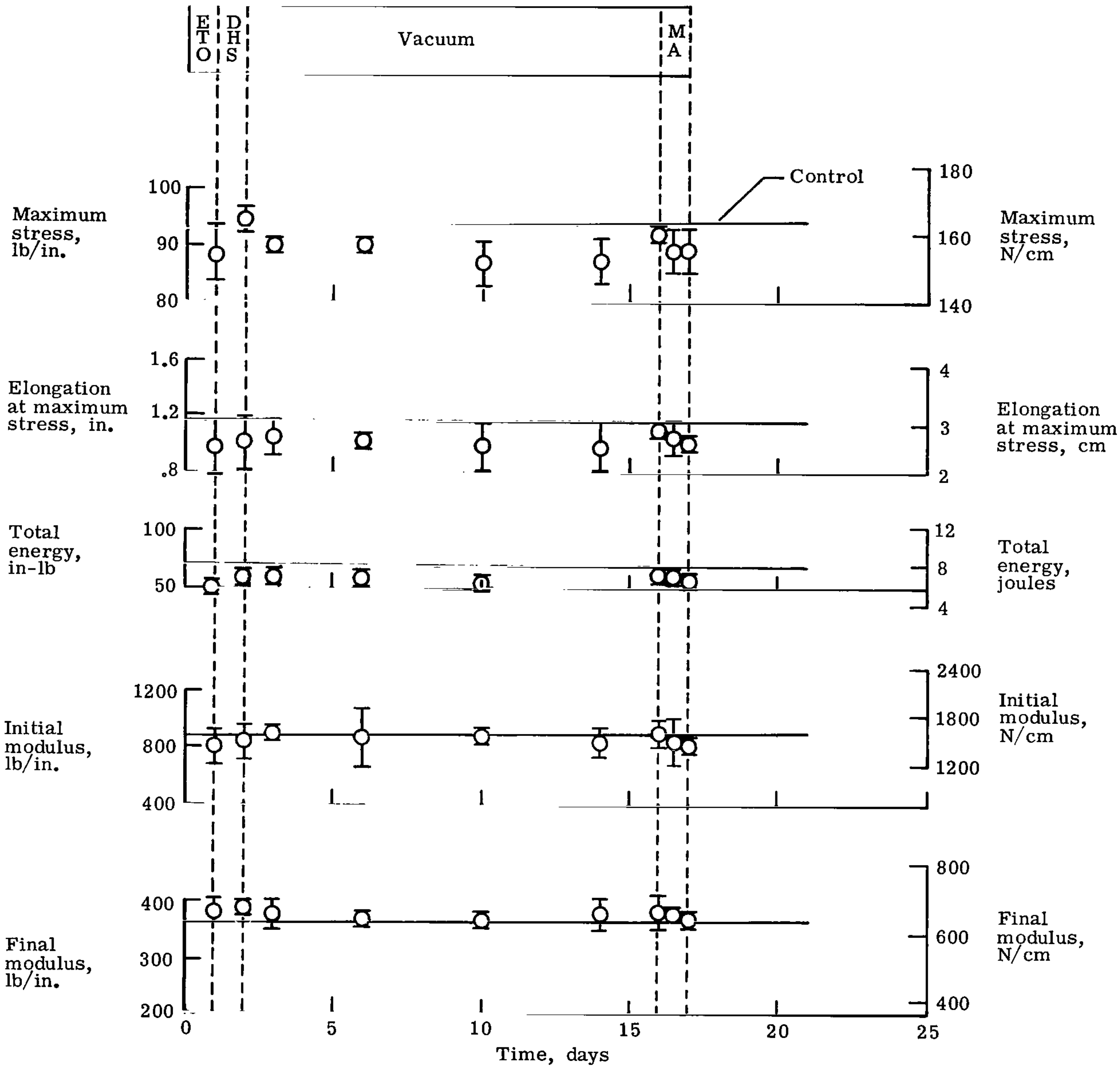


Figure 10.- Variation in mechanical properties after exposure to ethylene oxide, dry heat, vacuum, and Martian atmosphere.

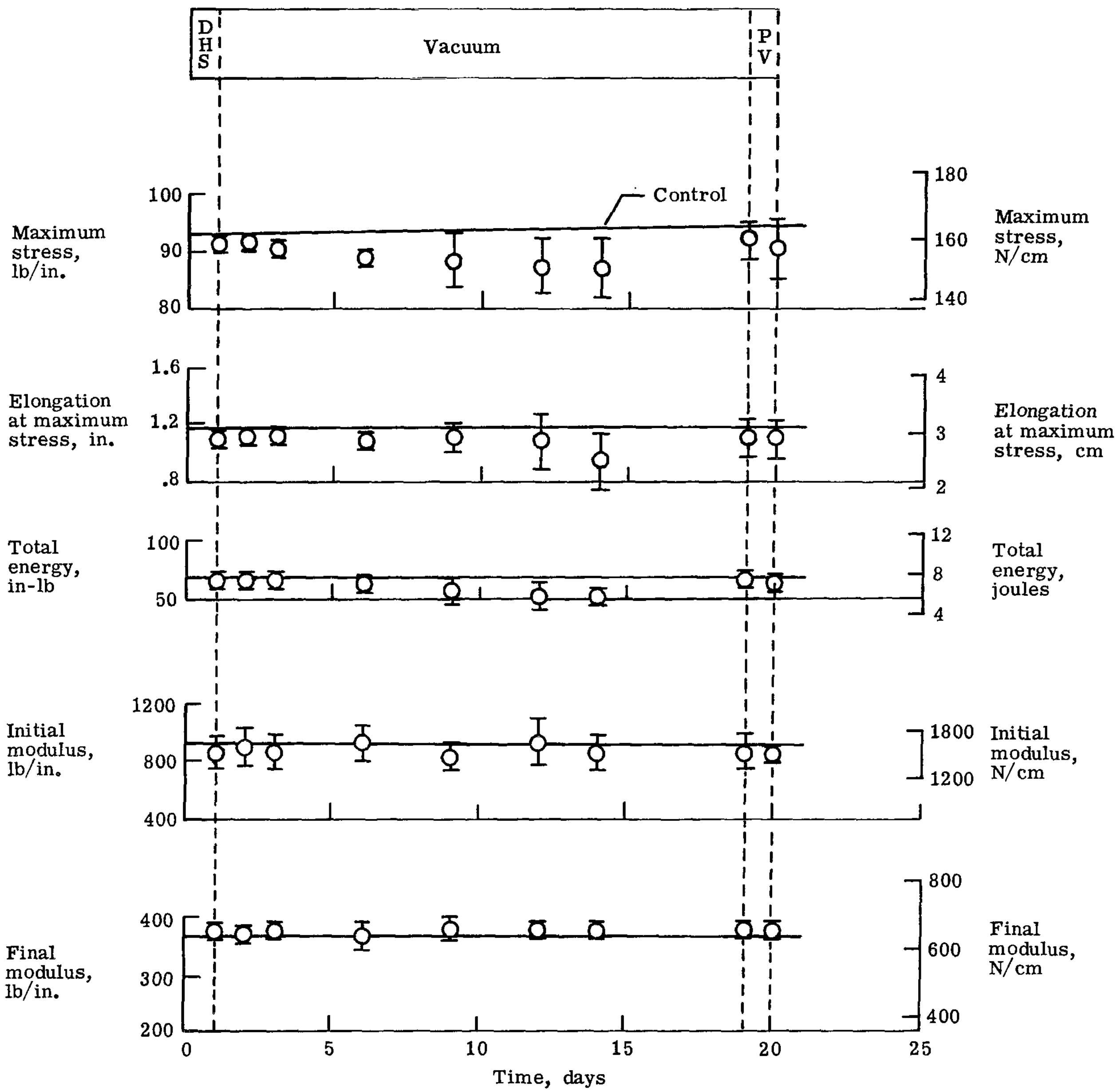


Figure 11.- Variation in mechanical properties with time after exposure to dry heat sterilization and vacuum.

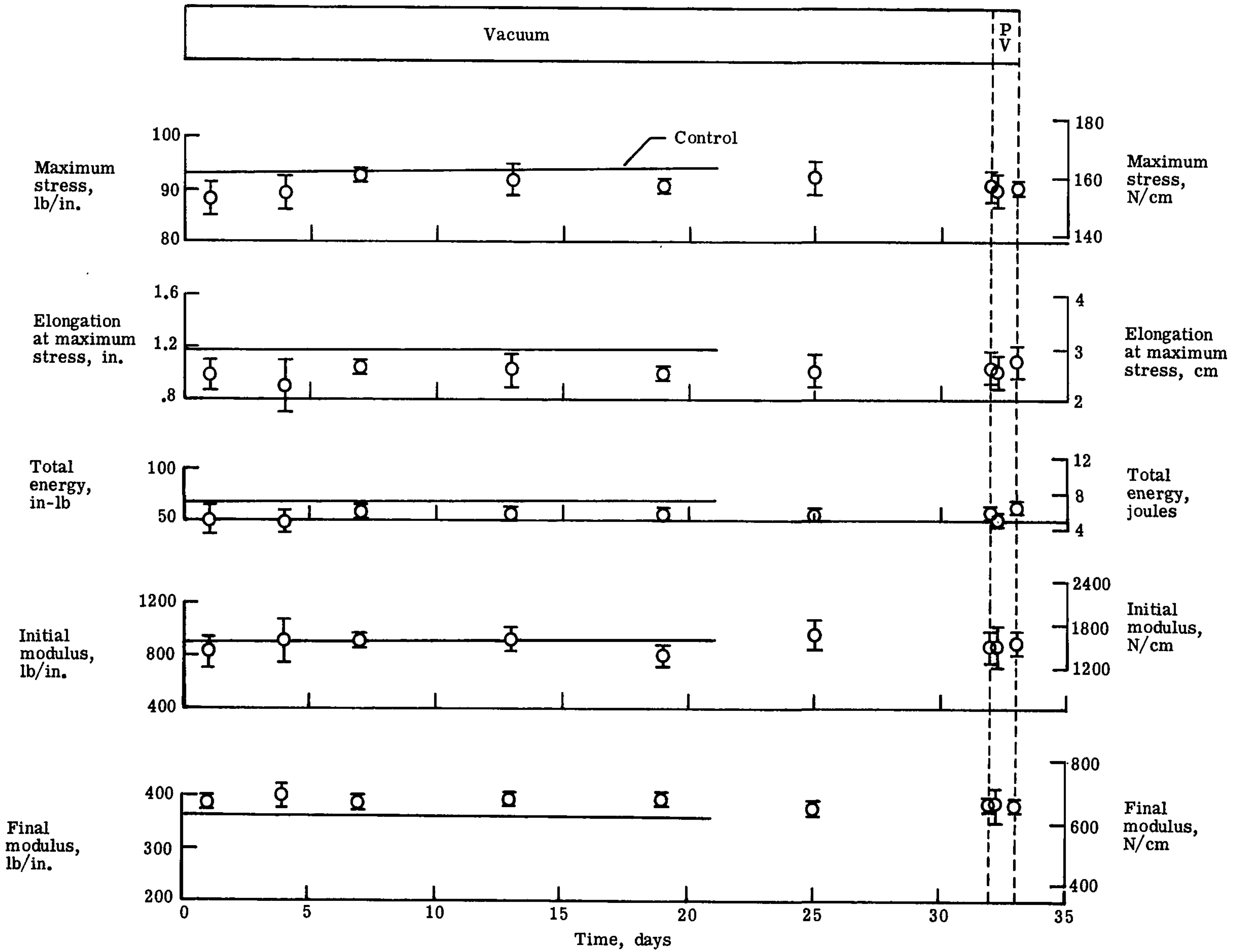


Figure 12.- Variation in mechanical properties with time after exposure to a vacuum environment.

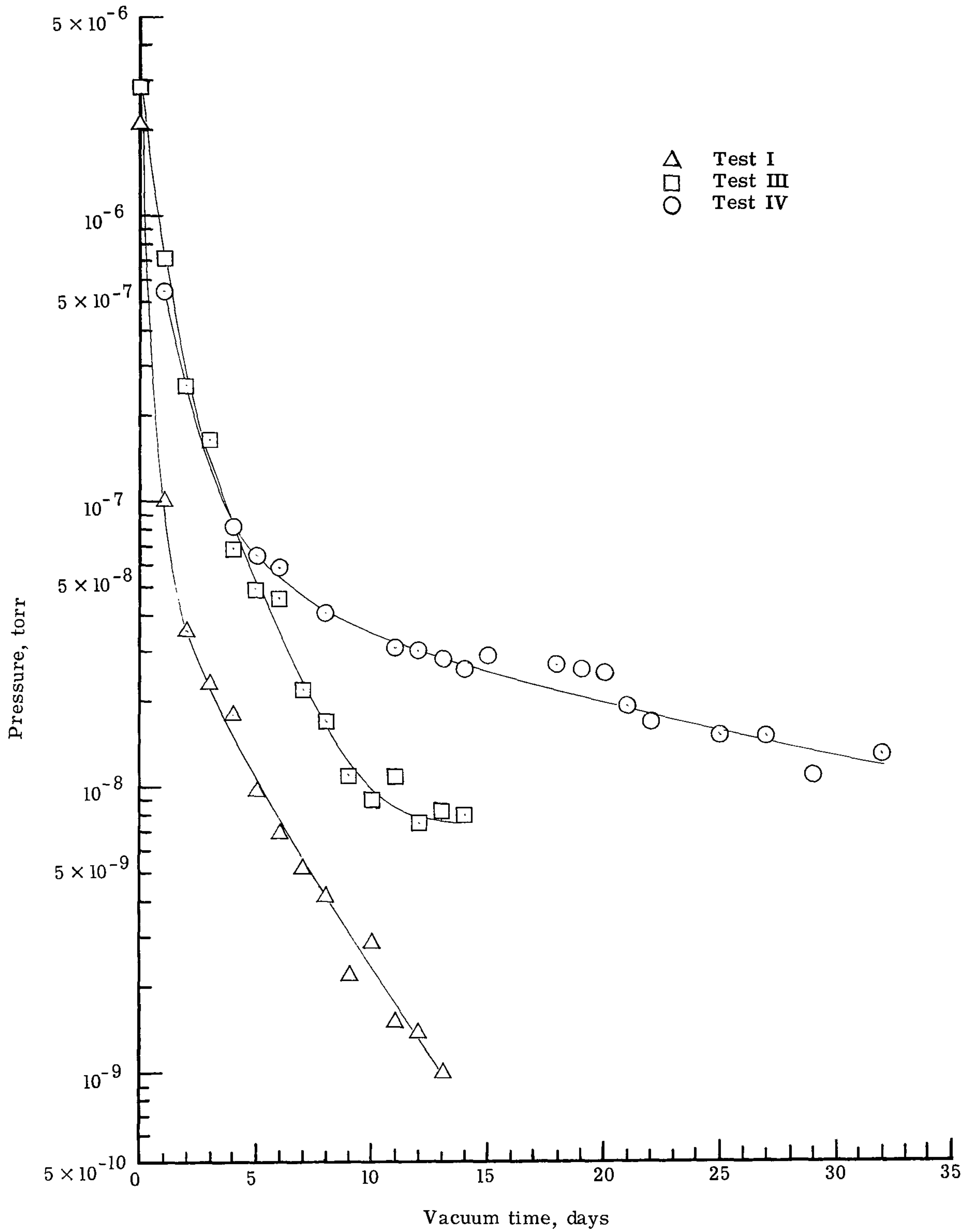


Figure 13.- Pressure as a function of time for three environmental tests.

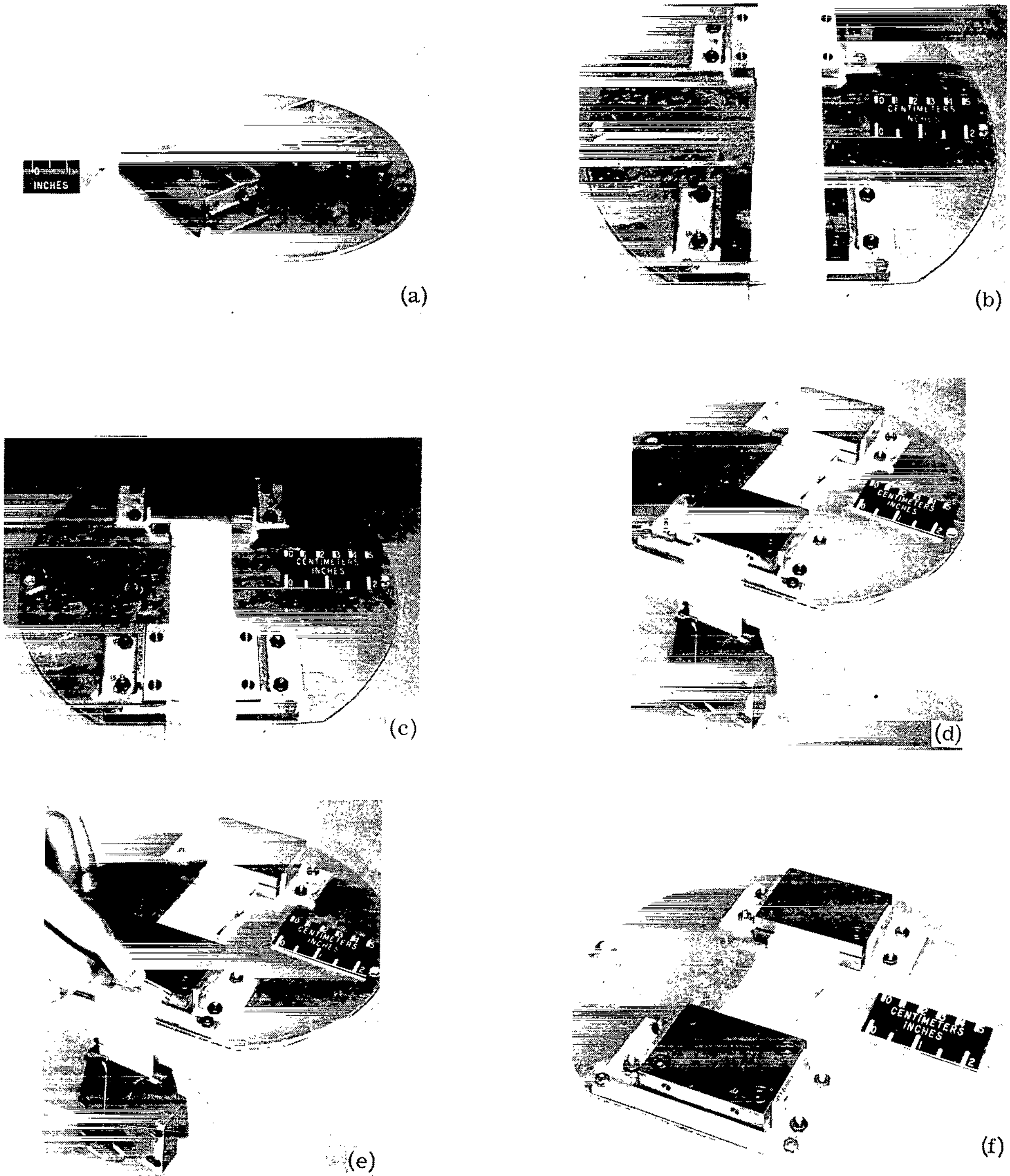


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Figure 14.- Sample preparation.

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